

How Can IT Enable the Simultaneous Pursuit of Green and Business Outcomes?: An Investigation of Smart Grid Innovations

Research-in-Progress

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Abstract

Sustainability has emerged as a key area of interest in response to a growing concern surrounding the adverse effects of pollution, such as climate change and health problems. Given these concerns, firms need to re-evaluate their traditional bottom line measures. We conceptualize production/distribution technologies (PDTs) and sense-making technologies (SMTs) as information technology (IT) innovations, whose combination allows firms to simultaneously achieve green and business outcomes. We focus on investments directed at PDTs and SMTs, which allows for a better understanding of the nature of the interdependencies between these two types of IT innovations. We propose the use of stochastic frontier analysis for business and green goals. We situate our study in the context of the U.S. Electric Utility Industry (EUI). This industry has been investing heavily in the Smart Grid over the past decade. Investments in the Smart Grid have been used to improve efficiency and facilitate environmental sustainability.

Keywords: IT Business Value, Sustainability, Green IS, Firm Performance, Electric Utility Industry

Introduction

Attention to sustainability issues has emerged as a key area of interest in recent years due to widespread public concern about the environment. This concern has risen in response to growing awareness of issues such as climate change and health effects that arise from pollution. For example, emissions, such as carbon dioxide (CO₂), sulfur dioxide (SO₂), and nitrogen oxide (NO_x) are suggested to impair human health and the environment. In particular, these emissions when combined in the atmosphere form fine particles, which contribute to an “increased incidence of premature death, aggravation of respiratory and cardiovascular illness (which can lead to hospitalizations and emergency room (ER) visits for children and those with heart or lung disease), decreased lung function and symptomatic effects (including acute bronchitis, particularly in children and asthmatics), and increased work loss days, school absences, and emergency room visits” (EPA 2014). Furthermore, emissions contribute to acidic compounds, which harm lakes and streams (i.e. make it difficult for some fish and other aquatic species to survive, grow, and reproduce), as well as forests and trees (i.e. acid rain, which can chemically alter the soil). Additionally, large amounts of nitrogen deposits can damage coastal water quality causing massive die-offs of marine plants and animals. These effects are non-trivial. According to the U.S. Government Accountability Office (GAO), in 2010, the U.S. spent \$8.8 billion on climate change. Yet this number does not account for the increased health costs that are associated with emissions, such as increased ER visits. Therefore, there is a vested interest in investigating sustainability.

With “green” or “sustainable” outcomes becoming increasingly relevant, firms need to re-evaluate the reliance on traditional measures of success (Chen et al. 2009), such as profitability. They need to evaluate their performance on green and sustainability outcomes as well. Indeed, the triple bottom line (people, planet, and profit) requires firms to address the various goals simultaneously rather than as a trade-off or zero-sum game (Porter and Kramer 2006). In an interview of CEO Muhtar Kent of Coca Cola, he sums up corporate social responsibility with regards to sustainability, “You cannot preserve and promote any sustainability efforts in the world today if they don’t have an economic benefit also” (Ignatius 2011). Therefore, to respond to the societal challenge of sustainability, firms need to develop the capabilities to simultaneously achieve economic and environmental outcomes.

While the field of information systems (IS) has paid some attention to sustainability, it has been focused more on reducing the direct impact of information technology (IT) use, such as increasing energy efficiency of data centers or recycling electronic waste. Less attention has been paid to the potential that IT has to enable environmental sustainability (Dedrick 2010) and the simultaneous pursuit of economic and environmental outcomes.

Previous research on the impacts of IT has linked investment in IT to various outcomes, such as firm output (productivity (Brynjolfsson and Hitt 1996) and organizational performance (Barua et al. 1995; Rai et al. 2006; Santhanam and Hartono 2003; Zhu and Kraemer 2002)), market perspectives (consumer welfare (Hitt and Brynjolfsson 1996), accounting profit (Bharadwaj 2000; Weill 1992), and market valuation (Bharadwaj et al. 1999; Brynjolfsson and Yang 1997; Dos Santos et al. 1993)), and firm risk (Dewan and Ren 2011). These outcomes have been looked at independently and it has been noted that it seems “logically impossible to maximize in more than one dimension at the same time unless the dimensions are monotone transformations of one another” (Jensen 2002). Yet, some researchers have found that environmental performance does have a positive impact on the firm’s financial performance (Orlitzky et al. 2003; Russo and Fouts 1997; Waddock and Graves 1997). Thus there may be conditions under which it is possible to achieve both types of outcomes—business and green—at the same time that have been overlooked in the IT value literature. Yet, these outcomes are not independent but interdependent, requiring firms to re-consider how they combine their various technologies to be effective.

We distinguish between two types of IT innovations: production/distribution and sense-making. *Production/distribution* technologies (PDT) enable the physical transformation processes of raw materials and the physical transport of goods/services to customers. Whereas, sense-making technologies (SMT) enable us to turn an ongoing complex world into a “situation that is comprehended explicitly in words and that serves as a springboard into action” (Im and Rai 2013; Weick et al. 2005). SMTs achieve this through the granular observation and analysis of behaviors in a system. For example, they can generate greater visibility of the physical stocks and flows, and events/exceptions associated with the production process (Rai et al. 2006). Furthermore, they can be used to understand the end-to-end sourcing-production-distribution process, to improve awareness of how the process is actually executed versus how it is described, and to discern patterns. Firms invest in these IT innovations to maximize efficiency, reliability, resiliency, and stability, while at the same time being environmentally conscious, i.e., reducing emissions. While prior research has revealed that IT capabilities for sense-making can be used to develop and enhance inter-organizational relationships (Im and Rai 2013), few studies have focused on the complementary nature of investments in IT innovations for production/distribution *and* sense-making.

As firms expand their relevant outcome set from business outcomes to include green outcomes, the opportunity for IT to build awareness and foster learning about itself also increases. While we understand that creating value from IT resources requires investments in a mutually reinforcing system of technologies, competencies, and practices (Aral and Weill 2007; Rai and Tang 2010; Tanriverdi 2006), it is important to uncover how PDTs and SMTs interact with each other to *simultaneously* affect green and business outcomes. As such, we evaluate how investments in PDTs and SMTs interact to affect the simultaneous pursuit of business and green outcomes, thereby addressing a key problem standing in the way of sustainability initiatives: the argument that these outcomes are in tension and cannot be effectively managed simultaneously. Our focus on investments directed at PDTs and SMTs, in contrast to the aggregate level of IT investments as in much IT impacts work, enables us to tease apart the nature of the interdependencies between these two classes of technologies in achieving green and business outcomes, thereby safeguarding against the deadly mistake in managing IT investments wherein complements and substitutes are conflated (Milgrom and Roberts 1995; Rai and Tang 2010; Siggelkow 2001; Sinha and Van de Ven 2005). More specifically, we are interested in how PDTs will need to be combined with SMTs to effectively achieve business and green outcomes simultaneously, since IT enables the process of learning/sense-making, which gains importance when there is a greater level of interdependence between decision choices (Levinthal 1997). Motivated by these gaps, we focus on the following research question: *How can investments in SMTs be combined with investments in PDTs to jointly optimize business and green outcomes?*

To address this research question, we propose the use of stochastic frontier analysis for both business and green outcomes. We draw on production theory and the theory of complementarities to understand how IT investments can be directed to achieve economic and environmental outcomes. We situate our study in the context of the U.S. Electric Utility Industry (EUI). This industry has been

investing heavily in the Smart Grid over the past decade to improve efficiency and facilitate environmental sustainability, providing an ideal context for our study.

Theoretical Development

We develop our conceptualization in the following manner leading to our proposed model and hypotheses. Figure 1 presents our model of a firm's PDT investments impacting green and business outcomes differentially when combined with investments in SMTs. First, we identify business and green outcomes as the key outcomes of concern for organizations. Second, we conceptualize PDT and SMTs as technological innovations. Third, we present the case for complementarities between PDT and SMTs. Fourth, we develop hypotheses on when investments in PDT and SMTs will create greater green and business outcomes.

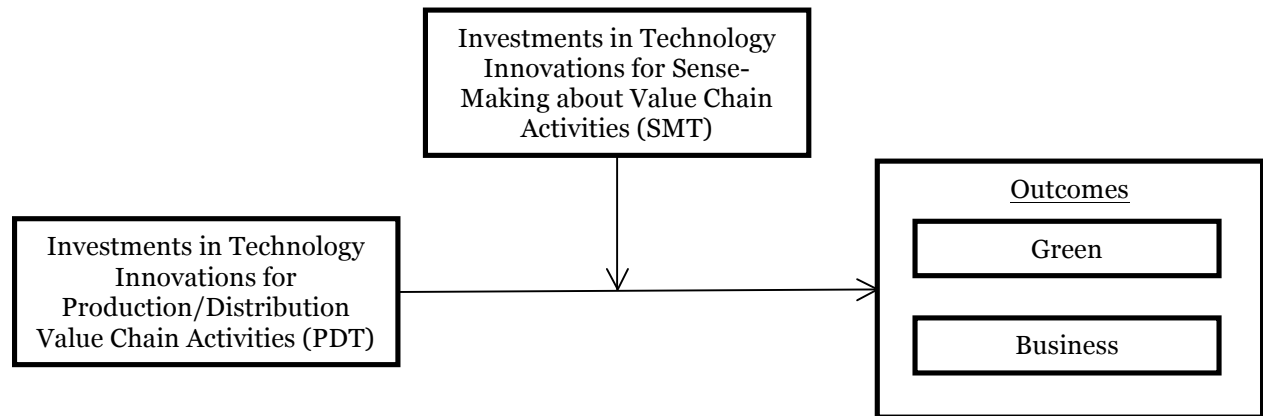


Figure 1: Research Model

Business Outcomes

Business outcomes of IT have previously been studied extensively (Bharadwaj 2000; Bharadwaj et al. 1999; Devaraj and Kohli 2003; Dewan and Ren 2011; McKeen and Smith 1993; Rai et al. 2006). We are concerned with a firm's performance relative to others. Firm profitability and operational expense are important dimensions of business outcomes. Firms need to achieve profitability to remain competitive, as well as balance operational expenses. We examine the business outcome of a firm as measured by net income and total operating expense.

Green Outcomes/Emissions

Environmental sustainability is one of the foremost concerns identified by the United Nations. This concern has permeated throughout many industries, such that many businesses are now embracing environmental sustainability as part of their corporate social responsibility (Esty and Winston 2006). Poor environmental practices result in waste, such as energy inefficiency, unused resources, and increased emissions, all of which decrease economic efficiency. Watson et al (2010) argue that these practices could be improved by green IS initiatives, specifically how information systems can be used to reduce energy consumption. In particular, reduced energy consumption—or greater efficiency in production—can lead to reduced emissions, such as CO₂, SO₂, and NO_x, and thus limit damaging effects. Another route that companies can take in reducing emission is to target improvements in technologies. For example, changing out old coal burning plants (which are the leading source of CO₂ emissions) with cleaner alternative energy sources that pollute less, such as natural gas. The big push on electric or clean-burning diesel engines is also in response to reducing toxic air pollutants. Other more demand-based approaches to reducing emissions come in the form of having individuals purchase Energy Star rated appliances, which are more environmentally friendly. Thus far, there has been limited research in IS examining how IT can help firms develop green outcomes (Melville 2010; Watson et al. 2010), motivating us to include green outcomes along with business outcomes in our investigation.

Conceptualization of PDT and SMTs as Classes of Value-Chain Technologies

Firms are challenged to develop effective value chain technologies that enable them to achieve multiple objectives that may be in tension. To gain knowledge about production and distribution in a changing uncertain environment, firms are investing in information-intensive technologies to facilitate learning and sense-making about their production and distribution processes. In particular, these technologies play a critical role because information provides the basis to manage physical process (e.g., production or distribution) in an organization (Ramaprasad and Rai 1996). Accordingly, we differentiate between the following value chain technologies: production/distribution technology (PDT) and sense-making technology (SMT) that enables learning about PDT.

PDT technologies are concerned with the efficiency of physical processes, which consume energy. These technologies have been largely confined to labor substitution and automation. Furthermore, these value chain technologies are not just firm-centric, but connect suppliers and customers (Barua et al. 2004). Thus, these technologies are meant to connect and coordinate production and distribution processes across locations and firm boundaries.

While industrial age organizations were focused primarily on the efficiency of production/distribution processes, contemporary organizations focus more on sense-making technologies. Sense-making technologies allows organizations to capture, transfer, and analyze information. In particular, these technologies allows the capture of information to support faster, more accurate responses for matching supply and demand, transfer of information to connect components to open architecture for real-time information and control, and inform actions based on the diagnosis and evaluation of the distribution and production system.

In sum, PDT and SMTs technologies are not just firm-centric, but connect suppliers and customers (Subramani 2004). Firms invest in each of these technological innovations to maximize efficiency, reliability, resiliency, and stability, while at the same time being environmentally conscious, i.e., reducing emissions.

Impact of PDTs on Business and Green Outcomes

Past research has observed that the impact of IT on productivity, as well as other measures of business value, can vary across and within industries due to differences in the role of IT (Devaraj and Kohli 2003). Furthermore, the ability for a firm to generate value from IT investments depends not only on strategy, but also on the structure of the industry (Dewan and Ren 2011), as well as market risks and regulation (Dewan and Min 1997). As firms create IT strategies, they can differentiate themselves in how they combine IT into core production and market exchange processes (PDT). Thus, variation in the use of IT capabilities can even occur within an industry. Christiansee and Venkatram (2002) describe how firms in the airline industry exhibited heterogeneity in their ability to develop computerized reservation systems, resulting in considerable control over their distribution channels, leading to increased market share and return on investments. In our context, PDTs are designed to increase production, transportation, and consumption efficiency, improve reliability, integrate renewable energy into the grid, increase economic efficiency, and reduce emissions (DOE 2013). Accordingly, we expect investments in PDTs to improve business and green outcomes, which leads us to hypothesize:

H1: PDTs have a positive effect on (a) business outcomes and (b) green outcomes.

Complementarities of PDTs and SMTs

We expect firms to realize greater benefits with respect to business and green outcomes from investments in PDTs if they combine them with investments in SMTs. We identify three reasons as to why these two types of technological investments are complementary and why firms will incur penalties in outcomes when they overlook interactions between two related technologies or mistake them for substitutes (Milgrom and Roberts 1995; Rai and Tang 2010). First, learning and sense-making are required to manage production and distribution when the business system is characterized by high interdependence of customers, the firm, and suppliers (Teece 1980). In the EUI context, firms now need to coordinate production and distribution across a complex network of customers, wholesale markets, regulators, and customers, making learning and sense-making about this complex system important. Second, the complementarity between sense-making and production and distribution can be expected to increase when a business seeks to transition from well-established technologies to newer innovations

(Teece 1986). In the EUI context, smart-grid innovations are relatively novel, making it important to focus not only on innovations in production and distribution but also on the capabilities to learn about how to effectively use these novel technologies that are implemented. Third, the complementarity between sense-making and production and distribution can be expected to increase when a firm is striving to manage a performance landscape with interdependencies among outcomes. In the EUI context, firms require the capabilities to learn about how its strategies and actions, in the changing context of the market in which it operates, affects business and green outcomes (Tanriverdi et al, 2010). Given the above arguments, we propose the following three hypotheses:

H2: *The marginal return to business outcomes from investments in PDT innovation increases with increases in accompanying investments in SMT innovation—i.e., investments in PDT and SMT are complementary for business outcomes.*

H3: *The marginal return to green outcomes from investments in PDT innovation increases with increases in accompanying investments in SMT innovation— i.e., investments in PDT and SMT are complementary for green outcomes.*

H4: *The complementarity between investments in PDT and SMT innovations to optimize both business and green outcomes is greater than the complementarity between investments in PDT and SMT to optimize either business outcomes or green outcomes*

Empirical Study

Investigative Context

We situate our study in the U.S. electric utility industry. This is an ideal setting for our study as it enables us to control for the product characteristics given that electricity is a unique commodity: it cannot be efficiently stored and its characteristics are standardized and differ only in the production location. Therefore, supply has to match demand at any time period to avoid shortages, i.e., production and consumption happen simultaneously. As a commodity, electricity can be traded in volume and can experience price volatility. Also, there are regulatory standards on service reliability (e.g., to safeguard against brownouts/blackouts) that must be adhered to. The EUI has a three-stage linear value chain: power generation to transmission (long-haul transmission from generation facilities to distribution sites) to distribution (distribution sites to consumers). We focus on investor-owned power generation firms in the EUI. To position this choice in context, there are approximately 210 investor-owned electric utilities, 2009 publicly-owned electric utilities, 883 consumer owned rural electric cooperatives and 9 Federal electric utilities. Total generating capacity was approximately 995 Gigawatts (2007) for the industry as a whole. In 2007, the annual revenue from electric operations from major US investor-owned electric utilities was \$253 Billion (EIA 2011). Investor owned electric utilities represent 6% of the total number of electric utilities and approximately 38% of utility installed capacity, 42% of generation, 66% of sales and 67% of revenue in the US. Publicly owned utilities represent about 61% of utilities, 9% of generating capacity, 8% of generation, 15% of sales and 13% of revenue (EIA 2011). Thus it is appropriate to focus on investor-owned firms as they represent the largest fraction of generation, sales, and revenue.

The EUI is governed by various agencies. At the federal level, the Energy Information Administration (EIA) collects, analyzes, and publicizes energy information that promotes policymaking and the Federal Energy Regulatory Commission (FERC) regulates interstate transmission of natural gas, oil, and electricity. Interstate sales of electricity on the wholesale market and by public utilities (e.g. investor-owned utilities, power marketers, independent power producers, and non-exempt electric cooperatives) are subject to regulation by FERC.

The Smart Grid

The Smart Grid “refers to a class of technology people are using to bring the utility electricity delivery systems into the 21st century, using computer-based remote control and automation” (2013). The grid has become smart, as digital technologies have allowed for two-way communication between the utility and its customers, as well as sensing along transmission lines. The Smart Grid has become a network of interconnections supported by production/distribution technologies that manage electricity and information technologies that manage information about electricity. Since electricity cannot be easily stored, it is imperative to align supply and demand, i.e. disruptive technological innovations are not tolerated. The Smart Grid consists of controls, computer automation, and new technologies and

equipment working together (DOE 2013). PDT technologies in the context of the Smart Grid are advanced components and substations as well as advanced control methods. In the Smart Grid, advanced components are targeted at superconductivity, fault tolerance, storage, power electronics, and diagnostics components that change the original abilities of grid, while advanced control technologies enable diagnosis and provide solutions to grid disruptions or outages. Sense-making technologies (SMT) in the Smart Grid enable advanced sensing and measurement, integrated communications and security, and decision support systems. Collectively, these technologies (PDT and SMT) allow for more efficient transmission of electricity, quicker restoration of electricity after power disturbances, reduced operations and management costs for utilities, lower power costs for consumers, reduced peak demand (which will also help lower electricity rates), increased integration of large-scale renewable energy systems, better integration of customer-owner power generation systems, including renewable energy systems, and improved security (DOE 2013).

Business and Green Outcomes of EUI Firms

Firms that are able to leverage their technological investments enjoy superior business outcomes by either increasing firm revenues and/or decreasing firm costs (Bharadwaj 2000). Net Income is regarded as an appropriate measure of the value of IT (McKeen and Smith 1993). Total Utility Operating Expense can be seen as the total cost of operations and was selected because it was the most encompassing of a firm's costs (Mitra and Chaya 1996). These business outcomes are appropriate for this context as net income is an aggregated measure of firm profitability and firms are quite sensitive to changes in operating expenses.

All types of electric power plants have some impact or effect on the environment, some more than others. The Environmental Protection Agency (EPA) has recently adopted and proposed a series of regulations for electric utilities that have the potential to generate significant changes in the industry (Miller 2013). Utilities will have to decide how to respond to these new emission requirements. Currently, fossil fuels generate most of the electricity we use, about 69% in 2012. CO₂, SO₂, and NO_x have been identified as the most common emissions from the combustion of these fuels. CO₂ is a well-known greenhouse gas and a source of climate change. SO₂ has been linked to acid rain and NO_x contributes to ozone generation, which can irritate the eyes, damages lungs, and aggravate respiratory problems (EPA, 2013). Firms exhibit significant variation in the level to which they pollute. Within firms (i.e. at the plant level) there is also significant variation in emissions. The EUI is an ideal setting to understand how firms configure production and information technologies to facilitate both business value and environmental goals.

Panel Dataset Construction

Our dataset is comprised of firm-level data for the 2008-2010 period. Firm-level data was collected from the Energy Information Administration (EIA) and the Federal Energy Regulatory Commission (FERC). FERC requires all major electric utilities to file Form 1 annually and we draw our data from here. A major electric utility is defined as having (1) one million megawatt hours or more; (2) 100 megawatt hours of annual sales for resale; (3) 500 megawatt hours of annual power exchange delivered; or (4) 500 megawatt hours of annual wheeling for others (deliveries plus losses) (FERC 2014). The firms who file Form 1 produce approximately 80% of the electricity in the United States. Form 1 is a comprehensive financial and operating report. In this report, firms are required to disclose all major investments (defined as investments that are greater than 5% of the total construction-work-in-progress and greater than \$100,000) undertaken by a firm in a given year. Minor investments are grouped together as a single entry. We extracted Form 1 data, financial and operating reports, filed with FERC from 2008-2010. While each firm is required to annually file Form 1, we found that there was little uniformity of investment descriptions. We clarified these discrepancies via phone interviews with various conformity officers at the various firms. Data was also collected from the Environmental Protection Agency. The EPA requires all fossil-fuel-fired steam electric generating units of more than 73 megawatts (MW) heat input rate (250 million British thermal units per hour (MMBtu/hr)) to report emission statistics (72 FR 32717, June 13, 2007). Data from the EIA allowed for the integration of this data across the two sources.

Coding

Scheme

A coding criterion was developed to determine if an investment was directed at a PDT innovation, SMT innovation, maintenance (i.e., those technologies which supported the maintenance of the grid and evolved incrementally meaning they did not shift the capabilities of the grid), or other (investments that cannot be categorized due to lack of available information). These categories are mutually exclusive and collectively exhaustive in describing all firm investments.

Process

To facilitate the coding process, keywords were developed from the existing data. By examining the current data set as a whole, certain action words were repeated and thus selected as keywords. These keywords are appropriate as they are derived from the firm's reported pattern of actions. Therefore, while the researchers may have selected the keywords, the nature of the reported investment (self-reported line entries) reduces the selection bias.

One of the researchers randomly selected 5 companies over 3 years (2008-2010) to test the validity of the coding scheme. Any discrepancies found were discussed by both researchers. Furthermore, if there were still any disagreements, the literature was consulted to resolve the issue. An iterative coding process was adopted with each subsequent coding cycle yielding 5, 10, and 10 companies, for a total of 30 companies from 2008-2010.

Construct Operationalization

Table 1 presents the operationalization of measures.

Variables		Descriptions	Source
Name	Type		
Net Income	DV	Net Income of a firm in a given year	FERC
Operating Expense	DV	Total Utility Operating Expense by a firm in a given year	
SO ₂	DV	Firm aggregated sulfur dioxide emissions (tons) in a given year	EPA
NO _x	DV	Firm aggregated nitrogen oxide emissions (tons) in a given year	
CO ₂	DV	Firm aggregated carbon dioxide emissions (tons) in a given year	
SMT	IV	Average dollar amount spent by a firm in a given year on technologies that capture, transfer, and analyze information derived from the grid	FERC
PDT	IV	Average dollar amount spent by a firm in a given year on technologies targeted at the efficiency of physical processes associated with the production and distribution of electricity	
Maintenance	Control	Average dollar amount spent by a firm in a given year on technologies that support the maintenance of the grid and evolve incrementally, as they do not shift the capabilities of the grid	
OTH1	Control	Average dollar amount spent by a firm in a given year on investments that are capital investments for a plant	
OTH2	Control	Average dollar amount spent by a firm in a given year on investments that are geographic/customer specific investments	
OTH3	Control	Average dollar amount spent by a firm in a given year on investments that costs that cannot be categorized due to lack of information	
Fuel Efficiency	Control	Average plant efficiency by fuel type calculated as Btu content of a kWh of electricity (which is 3,412 Btu) divided by the heat rate	
Firm Age	Control	Number of years since the firm's incorporation	
Firm Size	Control	Firm aggregated net generation, exclusive of plant use (KWh)	
Firm Location	Control	Dummy variable for the principal NERC region of the state in which the firm conducts business	

Table 1: Operational Measures

Current Findings

Currently, we have finished coding a subsample of 30 firms. We developed a strong unbalanced panel dataset with 9,194 investment decisions as well as emissions and performance variables for these 30 firms from 2008-2010. Preliminary analysis of the subsample reveals significant variation in all variables of interest, net income, operating expense, SO₂, NO_x, CO₂, as well as PDTs and SMTs. Table 2 presents descriptive statistics.

Variable	Obs	Mean	Std. Dev.
PDT	84	\$5,327,227.14	\$9,439,803.29
SMT	79	\$7,847,732.00	\$16,202,786.00
Maintenance	88	\$5,270,247.00	\$7,560,865.45
OTH1	75	\$10,403,793.61	\$16,745,194.18
OTH2	72	\$5,748,862.72	\$12,936,606.95
OTH3	88	\$112,290,365.01	\$146,896,489.55
CO ₂ (tons)	57	25,442,295.14	22,094,897.48
SO ₂ (tons)	56	72,428.72	93,434.80
NO _x (tons)	56	24,455.49	24,776.94
Net Income	88	\$312,382,886.75	\$313,234,612.45
Total Utility Operating Expense	88	\$3,211,231,556.31	\$2,799,312,849.89
Net Generation	66	35,263,367,201.76	31,600,220,572.25
Firm Age (years)	90	81.83	29.77
Coal Efficiency	51	0.32	0.03
Oil Efficiency	27	0.20	0.10
Gas Efficiency	45	0.33	0.07
Nuclear Efficiency	31	0.32	0.01

Table 2: Descriptive Statistics

Future Directions

The data used here is a subsample of the full dataset to be developed. We plan on completing the coding process for all 200 firms across the time frame 2008-2010. The full dataset will be comprised of approximately 200 firms from 2000-2010, yielding approximately 200,000 investment decisions. We will test the hypotheses using stochastic frontier analysis (SFA) with the appropriate model specifications. SFA has been used in a variety of studies on production, cost, revenue, and profit and assumes that there is an optimal frontier goal (maximum output or minimum cost) that is comprised of a deterministic part and a stochastic part (Aigner et al. 1977). It also incorporates the amount by which one fails to reach the optimum or inefficiency. Therefore, a firm either operates on the frontier (if it is efficient) or below the frontier (if it is inefficient). As firms attempt to optimize green and business outcomes, some firms are likely to be more efficient than others. By using SFA, we will be able to establish efficiency scores for firms in their pursuit of business and green outcomes and evaluate how these scores relate to the use of PDTs, SMTs, and their complementarity.

Contribution

Our study contributes to the IT business value, IT capabilities and environmental sustainability literatures by surfacing how investments in SMTs can be combined with investments in PDTs to jointly optimize business and green outcomes. The results will inform the policy discourse on smart grid technologies and the business and green outcomes resulting from investments in these innovations.

References

- Aigner, D., Lovell, C., and Schmidt, P. 1977. "Formulation and Estimation of Stochastic Frontier Production Function Models," *Journal of Econometrics* (6:1), pp. 21-37.
- Aral, S., and Weill, P. 2007. "IT Assets, Organizational Capabilities, and Firm Performance: How Resource Allocations and Organizational Differences Explain Performance Variation," *Organization Science* (18:5), pp. 763-780.
- Barua, A., Konana, P., Whinston, A., and Yin, F. 2004. "Assessing Net-Enabled Business Value: An Exploratory Analysis," *MIS Quarterly* (28:4), pp. 585-620.
- Barua, A., Kriebel, C., and Mukhopadhyay, T. 1995. "Information Technologies and Business Value: An Analytic and Empirical Investigation," *Information Systems Research* (6:1), pp. 3-23.
- Bharadwaj, A. 2000. "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation," *MIS Quarterly* (24:1), pp. 169-196.
- Bharadwaj, A., Bharadwaj, S., and Konsynski, B. 1999. "Information Technology Effects on Firm Performance as Measured by Tobin's q," *Management Science* (45:7), pp. 1008-1024.
- Brynjolfsson, E., and Hitt, L. 1996. "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending," *Management Science* (42:4), pp. 541-558.
- Brynjolfsson, E., and Yang, S. 1997. "The Intangible Benefits and Costs of Computer Investments: Evidence from Financial Markets," International Conference on Information Systems, Atlanta, GA.
- Chen, A., Watson, R., Boudreau, M., and Karahanna, E. 2009. "Organizational Adoption of Green IS and IT: An Institutional Perspective," International Conference on Information Systems, Association for Information Systems.
- Christiaanse, E., and Venkatraman, N. 2002. "Beyond Sabre: An Empirical Test of Expertise Exploitation in Electronic Channels," *MIS Quarterly* (26:1), pp. 15-38.
- Dedrick, J. 2010. "Green IS: Concepts and Issues for Information Systems Research," *Communications of the Association for Information Systems* (27:11), pp. 173-184.
- Devaraj, S., and Kohli, R. 2003. "Performance Impacts of Information Technology: Is Actual Usage the Missing Link?," *Management Science* (49:3), pp. 273-289.
- Dewan, S., and Min, C. 1997. "The substitution of information technology for other factors of production: a firm-level analysis," *Management Science* (43:12), pp. 1660-1675.
- Dewan, S., and Ren, F. 2011. "Boundaries: Impact on Firm Risk and Return Performance," *Information Systems Research* (22:369-388), pp.
- DOE. 2013. The Smart Grid. <<http://www.smartgrid.gov>>
- Dos Santos, B., Peffers, K., and Mauer, D. 1993. "The Impact of Information Technology Investment Announcements on the Market Value of the Firm," *Information Systems Research* (4:1), pp. 1-23.
- EPA. 2014. "Human Health and Environmental Effects of Emissions from Power Generation," EPA.
- Esty, D., and Winston, A. 2006. *Green to Gold: How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage* Yale University Press, New Haven, CT.
- FERC. 2014. Form No. 1. <<https://http://www.ferc.gov/docs-filing/forms.asp> - 1>
- Hitt, L., and Brynjolfsson, E. 1996. "Productivity, Business Profitability, and Consumer Surplus: Three Different Measures of Information Technology Value," *MIS Quarterly* (20:2), pp. 121-142.
- Ignatius, A. 2011. "Shaking Things Up at Coca-Cola," *Harvard Business Review*, pp. 94-99.
- Im, G., and Rai, A. 2013. "IT-Enabled Coordination for Ambidextrous Interorganizational Relationships," *Information Systems Research* (Articles in Advance), pp.
- Jensen, M. 2002. "Value Maximization, Stakeholder Theory, and the Corporate Objective Function," *Business Ethics Quarterly* (12:2), pp. 238.
- Levinthal, D. 1997. "Adaptation on Rugged Landscapes," *Management Science* (43:7), pp. 934-950.
- McKeen, J., and Smith, H. "The Relationship Between Information Technology Use and Organizational Performance," in: *Strategic Information Technology Management: Perspectives on Organizational Growth and Competitive Advantage*, R. Banker, R. Kauffman and M. Mahmood (eds.), Idea Group Publishing, Harrisburgh, PA, 1993, pp. 405-444.
- Melville, N. 2010. "Information Systems Innovation for Environmental Sustainability," *MIS Quarterly* (34:1), pp. 1-21.
- Milgrom, P., and Roberts, J. 1995. "Complementarities and Fit Strategy, Structure, and Organizational Change in Manufacturing," *Journal of Accounting and Economics* (19:2), pp. 179-208.

- Miller, P. 2013. "A Primer on Pending Environmental Regulations and their Potential Impacts on Electric System Reliability," Northeast States for Coordinated Air Use Management, Boston, MA.
- Mitra, S., and Chaya, A. K. 1996. "Analyzing Cost Effectiveness of Organizations: The Impact of Information Technology Spending," *Journal of Management Information Systems* (13:2), pp. 29-57.
- Orlitzky, M., Schmidt, F., and Rynes, S. 2003. "Corporate Social and Financial Performance: A Meta-Analysis," *Organization Studies* (24:3), pp. 403-441.
- Porter, M., and Kramer, M. 2006. "Strategy and Society: The Link Between Competitive Advantage and Corporate Social Responsibility," *Harvard Business Review* (84:12), pp. 78-92.
- Rai, A., Patnayakuni, R., and Patnayakuni, N. 2006. "Firm Performance Impacts of Digitally Enabled Supply Chain Integration Capabilities," *MIS Quarterly* (30:2), pp. 225-246.
- Rai, A., and Tang, X. 2010. "Leveraging IT Capabilities and Competitive Process Capabilities for the Management of Interorganizational Relationship Portfolios," *Information Systems Research* (21:3), pp. 516-542.
- Ramaprasad, A., and Rai, A. 1996. "Envisioning Management of Information," *Omega* (24:2), pp. 179-193.
- Russo, M., and Fouts, P. 1997. "A Resource-Based Perspective on Corporate Environmental Performance and Profitability," *Academy of Management Journal* (40:3), pp. 534-559.
- Santhanam, R., and Hartono, E. 2003. "Issues in Linking Information Technology Capability to Firm Performance," *MIS Quarterly* (27:1), pp. 125-153.
- Siggelkow, N. 2001. "Change in the Presence of Fit: The Rise, the Fall, and the Renaissance of Liz Claiborne," *Academy of Management Journal* (44:4), pp. 838-857.
- Sinha, K., and Van de Ven, A. 2005. "Designing Work Within and Between Organizations," *Organization Science* (16:4), pp. 389-408.
- Subramani, M. 2004. "How Do Suppliers Benefit From Information Technology Use in Supply Chain Relationships?," *MIS Quarterly* (28:1), pp. 45-73.
- Tanriverdi, H. 2006. "Performance Effects of Information Technology Synergies in Multibusiness Firms," *MIS Quarterly* (30:1), pp. 57-77.
- Teece, D. 1980. "Economies of Scope and the Scope of the Enterprise," *Journal of Economic Behavior & Organization* (1:3), pp. 223-247.
- Teece, D. 1986. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Research Policy* (15:6), pp. 285-305.
- Waddock, S., and Graves, S. 1997. "The Corporate Social Performance - Financial Performance Link," *Strategic Management Journal* (18:4), pp. 303-319.
- Watson, R., Boudreau, M., and Chen, A. 2010. "Information Systems and Environmentally Sustainable Development: Energy Informatics and New Directions for the IS Community," *MIS Quarterly* (34:1), pp. 23-38.
- Weick, K., Sutcliffe, K., and Obstfeld, D. 2005. "Organizing and the Process of Sensemaking," *Organization Science* (16:4), pp. 409-421.
- Weill, P. 1992. "The Relationship Between Investment in Information Technology and Firm Performance: A Study of the Valve Manufacturing Sector," *Information Systems Research* (3:4), pp. 307-333.
- Zhu, K., and Kraemer, K. 2002. "e-Commerce Metrics for Net-Enhanced Organizations: Assessing the Value of e-Commerce to Firm Performance in the Manufacturing Sector," *Information Systems Research* (13:3), pp. 275-295.